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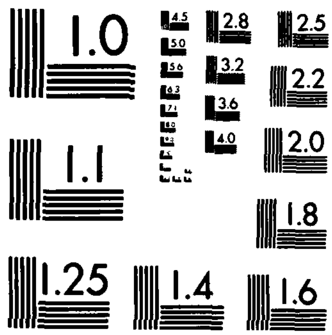
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16. Abstract
The purpose of this handbook is to provide a statistically sound method of estimating aircraft operations at non-towered airports from sampling counts. The handbook is written for planners, engineers, airport operators responsible for airport planning, and persons that collect data for FAA Airport Master Records (Form 5010.1). Many of these users will be familiar with general aviation airports, but not necessarily with statistical methods.

Accurate information on aircraft activity at non-towered airports is a major need of airport owners and operators as well as planners and administrators charged with the planning and development of the airport system. Unlike towered airports, where air traffic controllers keep constant tallies of activity, most non-towered airports have no accurate record of usage.

Obtaining accurate aircraft activity counts will provide a variety of benefits. Investment decisions can be made with more confidence if benefit-cost analysis is based on accurate information about use of the facility. Design criteria, which may have a significant impact on development and operating costs, can be more efficiently applied. Even when decisions are based on forecasts rather than present circumstances, accurate base data is necessary to make accurate forecasts of activity. Keywords:

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INTRODUCTION

Accurate information on aircraft activity at non-towered airports is a major need of airport owners and operators as well as planners and administrators charged with the planning and development of the airport system. Unlike towered airports, where air traffic controllers keep constant tallies of activity, most non-towered airports have no accurate record of usage.

Obtaining accurate aircraft activity counts will provide a variety of benefits. Investment decisions can be made with more confidence if benefit-cost analysis is based on accurate information about use of the facility. Design criteria, which may have a significant impact on development and operating costs, can be more efficiently applied. Even when decisions are based on forecasts rather than present circumstances, accurate base data is necessary to make accurate forecasts of activity.

The purpose of this handbook is to provide a statistically sound method of estimating aircraft operations at non-towered airports from sample counts. The handbook is written for planners, engineers, airport operators responsible for airport planning, and persons that collect data for FAA Airport Master Records (form 5010-1). Many of these users will be familiar with general aviation airports, but not necessarily with statistical methods.

Sampling and Estimating Procedures

Methods of counting aircraft operations fall into two general categories: visual methods, which require the observer to be physically present at the airport; and mechanical methods, such as acoustical and pnuematic tube counters, which collect information without requiring the full-time presence of an observer. All methods of counting aircraft operations, both visual and mechanical, have usually been found to be too expensive to permit continuous counts over long periods. The alternative is to use sample counts to estimate activity over any given period.

Estimating procedures generally fall into four categories. The first is based on the recollections of fixed base operators, managers or others associated with a particular airport. When compared to actual observations these estimates have usually been found to be inaccurate, either because it is the busy periods that stick in the minds of those making the estimates, or because a significant number of operations, particularly local operations, are unnoticed. For example, operations estimates on the FAA 5010-1 form are usually derived from recollections of annual activity. Comparisons of operations estimates based on sample data to operations estimates reported on 5010-1 forms for a number of Northwest airports in 1981 and 1983 indicate that overestimates of 80 percent or more on 5010-1 forms were not uncommon.

A second type of estimating procedure relies on a previously established relationship between aircraft operations and an independent factor. For example, a ratio of operations per based aircraft is often used to estimate operations. This method is sometimes useful to make system-wide estimates when no other information is available. However, the system-wide ratio applied to any individual airport within the system may be extremely inaccurate. Also, the procedure assumes that accurate operations estimates are available to develop the ratio of operations per based aircraft.

A third type of estimating procedure relies on an accurate measure of operations over a brief sample period. These sample counts are used in conjunction with independent data, such as operations from a tower airport, to estimate non-towered operations throughout the remainder of the year. The reliability of these estimates is questionable because there is no way to determine in advance whether or not the independent data (such as tower operations) are really related to operations at the non-towered airport. For example, a study comparing 1983-84 operations data between four towered and seven non-towered airports indicates tower operations data do not provide reliable estimates of operations at non-towered airports.[1] Similar results were obtained from a 1981 study of 9 towered and 24 non-towered airports in the Northwest.[2]

The fourth and most reliable method of estimating aircraft activity is based on statistical sampling of aircraft operations.

Statistical Sampling

Statistical sampling is a method whereby all operations have an equal chance of being sampled. For this reason it is often called random sampling. Benefits of statistical sampling for estimating aircraft operations may be summarized into four categories:

1. It ensures sampled operations are representative of operations throughout the year.
2. It provides an estimate of operations during a given period without the costly counting of all aircraft activity;
3. It allows estimates of operations to be made with a known degree of precision; and
4. It allows resources to be used efficiently by relating size (and cost) of the sample to the level of precision required.

[1]Unpublished study of towered and non-towered airport operations data; Oregon Department of Transportation, 1984.

[2]Aircraft Activity Counter Demonstration Project, Final Report, Aeronautics Division, Oregon Department of Transportation, 1982.

Statistical sampling differs from other methods of sampling in that it relies on the random choice of operations. This procedure ensures the sampled operations are representative of operations throughout the year. It prevents known or unknown factors from affecting the sample and skewing the resulting estimate. For example, if aircraft operations were sampled only on sunny days, the results would likely be an overestimate of total operations. By avoiding rainy days, the sampler would not get a representative sample of the entire year. Random sampling ensures that operations are sampled independently of the sampler's preferences and biases.

With respect to the second point, reliable information about aircraft operations likely would not be available without the cost savings of a sample estimate. The cost of a visual count of all operations 365 days a year, 24 hours a day is prohibitive. The capital and maintenance costs of a mechanical count of all operations for a year is also very high.

An estimate of annual operations based on a sample of operations is much less costly than a complete count of annual operations. Sample data is collected using the same techniques, whether visual or mechanical, as would be used for a complete count of operations. However, most samples are based on 10% or less of the operations. Therefore, even allowing for some additional costs associated with sample planning and estimating, the cost of collecting sample operations data is much less than the cost of a full count.

Only statistical sampling provides both an estimate and a measure of the precision of the estimate. Other types of sampling can provide an estimate, but there is no valid way to determine how precise the estimate is. Precision of the estimate is as important as the estimate itself. If costly construction decisions or sensitive political decisions are being made based on the operations estimate, it is important to know if the estimate is very precise or only a ballpark estimate.

Precision of the estimate is measured by the sampling error, which is usually expressed as a percent of the operations estimate. For example, an estimate of 10,000 annual operations with a sampling error of plus or minus 10 percent at a 95 percent confidence level means that the user can be 95 percent confident that the true number of operations lies between 9,000 (-10%) and 11,000 (+10%). The usefulness of this estimate is much greater than an estimate of 10,000 operations with a sampling error of plus or minus 50 percent. In this case the true number of operations could lie between 5,000 and 15,000 operations.

Finally, because statistical sampling provides a measure of precision, it allows sample size and cost to be adjusted to the level of precision required for a particular airport or purpose. Generally, a more precise estimate requires a larger and more costly sample. A fairly precise operations estimate, and the funding necessary to achieve it, would be required for a decision to construct a full parallel taxiway costing $400,000. Conversely, a less precise, and less expensive, estimate would be adequate for a decision to add holding aprons at the ends of a runway for $15,000. Optimal sampling based on the required degree of precision allows more airports to be sampled, or one airport to be sampled more often, for a given number of dollars.

Annual Operations Estimates

Statistical sampling procedures presented in this handbook are primarily for estimating total annual operations. That is the statistic most commonly required and consistently compared among airports. Many other statistics, including number of operations that occur in various time periods, number of operations by aircraft type, number of local and itinerant operations, daily or hourly peaks, and other valuable information may also be estimated if the sample is correctly drawn. These statistics will be discussed after basic procedures for annual operations and precision estimates are presented.

The following chapters of the handbook explain the major steps in conducting a sample of aircraft operations and estimating total operations from the sample data:

1. Pre-Sample Planning,
2. Developing a Sampling Plan,
3. Collecting Sample Data,
4. Organizing Sample Data and Estimating Operations,
5. Estimating Distribution of Operations.

Each chapter includes an explanation of the process and an example to illustrate how the procedures are to be applied. Chapter 4 includes forms for tabulating data and estimating annual operations. The final chapter, Chapter 6, Methods of Collecting Sample Data, discusses and compares alternative methods of collecting data. Appendix A, Corrections for Loss of Sample Data, discusses common problems that occur in the sampling and estimating process and how to correct them. Appendix B, Statistical Derivation of Estimating Procedures, contains statistical equations for estimating operations and the precision of the estimate.

An Example: Tri-City State Airport

The entire sampling and estimating process becomes more clear when related to an actual example where it was applied. The Tri-City State Airport near Myrtle Creek, Oregon is used as an example throughout the handbook. A brief description of the sampling process and results of the sample for Tri-City State Airport are presented here as an overview of the entire sampling procedure. Each step is discussed in more detail in the following chapters.

Tri-City State Airport has no fixed base operator and is unattended most of the time. Prior to sample counts conducted in 1983 and 1984, the State Aeronautics

Division, which owns the airport, could not be sure if there were 500 or 15,000 operations per year at the airport. An estimate of 4,500 operations per year was being used for planning purposes.

During pre-sample planning it was determined that use of an acoustical aircraft activity counter was the most practical means to obtain a sample of operations. The sampling method was chosen based on the type of information desired. In addition to total annual operations it was also desireable to estimate seasonal operations and determine whether or not multi-engine aircraft were using the airport. It also would have been useful to know the local/itinerant split and the number of helicopter operations, but these could not be identified by the acoustical counter or any other known mechanical counting method.

A sampling plan was developed for the airport that would provide an estimate of annual operations with a desired level of precision. Weekly counts of operations were made in four seasons with two counts in each season. This allowed estimates of known precision for each season as well as for the year.

During each week sampled a Rens Aircraft Activity Counter was placed at the airport. The counter recorded the sounds of all departures during the week. Aircraft departures were tallied and daily departures were doubled to arrive at operations. Departures were also classified as single engine, multi-engine, or jet aircraft.

When the sample was completed, estimates of operations were made according to the procedures described in subsequent chapters of this handbook. Total annual fixed-wing operations were estimated to be 2,274, with a 29 percent sampling error. This sampling error means that the State Aeronautics Division can now be 95 percent confident that total fixed-wing operations at Tri-City State Airport in the 1983-84 period were between 1,624 (2,274 minus 29 percent) and 2,924 (2,274 plus 29 percent). Eighteen percent of these operations were estimated to be multi-engine aircraft. In addition, there were helicopters operating at the airport, but the number of these operations could not be determined from information collected by the acoustical counter. There were no jet operations recorded by the counter.

Tri-City State Airport was one of 17 Oregon airports counted during 1983-84. Average cost for each airport counted was about $1,200. (See Chapter 6 for a discussion of other sampling methods and their costs.)

1. PRE-SAMPLE PLANNING

A number of pre-sample planning decisions must be made before the sampling plan can be developed. Figure 1 summarizes the pre-sample decisions and how they relate to the subsequent steps in the sampling process.

Determine Information Needed

The most basic decision that must be made is determining what information is needed. In most cases, total annual operations will be the primary information required, but it may also be desirable to determine operations for shorter periods or peak operations for a given period. The sampling plan will differ based on whether an annual estimate, quarterly and annual estimates, or monthly, quarterly and annual estimates are desired. The more time periods for which an estimate is desired, the more constraints there will be on the sampling plan and the larger the sample size required.

Another decision that must be made during pre-sample planning is whether any information in addition to the count of operations needs to be collected at the time of the sample. If information about each operation is desired, such as hour of operation, type of operation (local, itinerant, commuter, etc.), or type of aircraft, then plans to obtain the information must be made. Once the sample has begun, it may be too late or too costly to modify the sample in order to obtain information not anticipated at the outset. If a subsample of operations is used as a lower-cost alternative for collecting information about some of the operations counted (see Chapter 5), it must also be planned prior to beginning the sample.

Choose Sample Method

The type of operations information needed will dictate the method used to collect the sample data. Some methods, such as pneumatic tubes, only register that an operation took place. Other methods, such as visual observation, can provide information about time and type of operation and type of aircraft. A comparison of different methods of collecting sample data and their capacity to gather information about operations is included in Chapter 6.

Determine Precision

In addition to determining what is to be estimated, the desired precision of the estimate must also be determined. The desired precision will determine the size of the sample necessary to achieve the level of precision. The desired precision should also be discussed in the pre-sample stage to ensure the resulting operations estimate will be adequate for the purpose for which the estimate will be used. The more crucial or costly the decision, the more precise the estimate should be.

Determine Cost and Funding

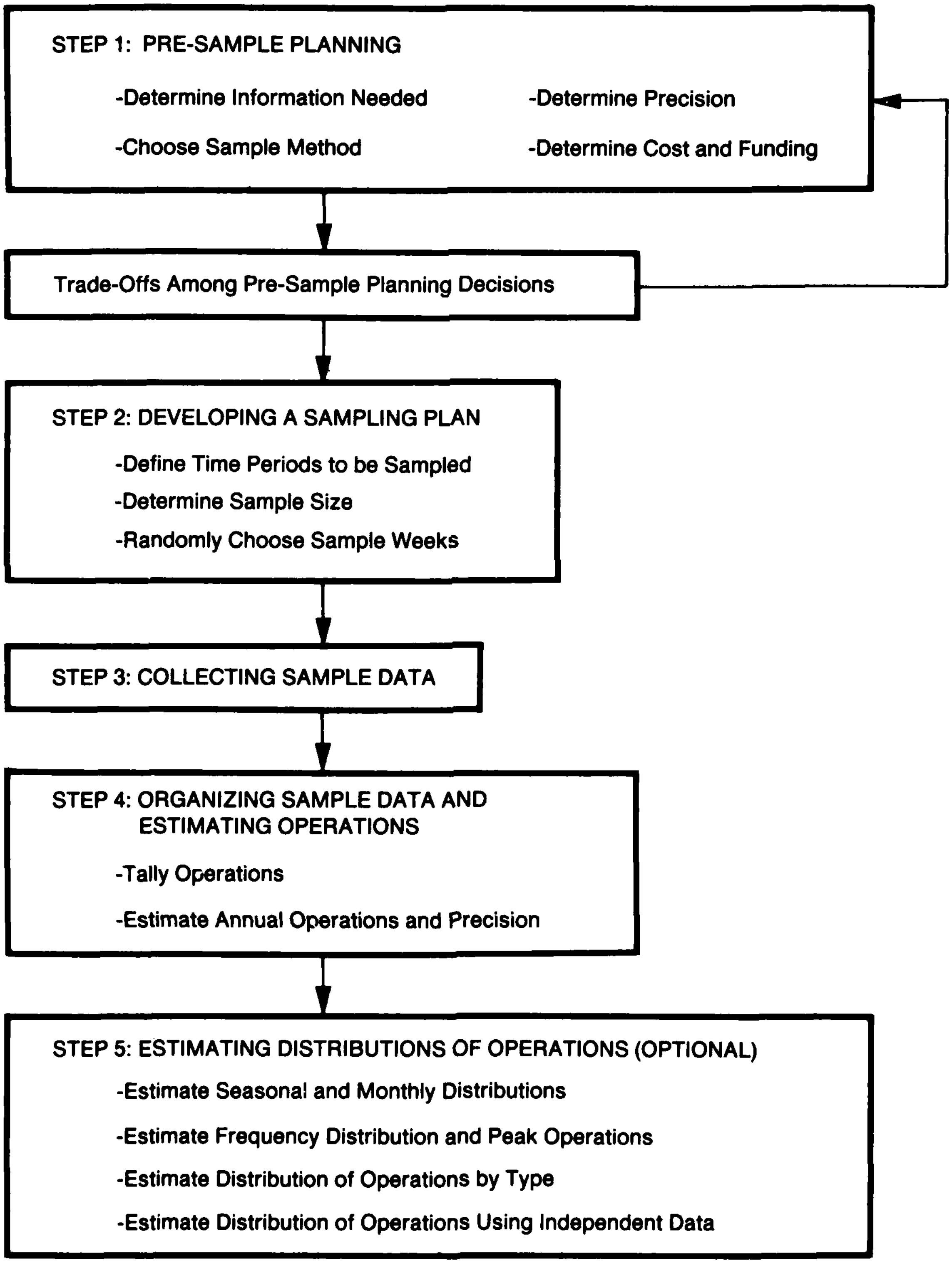
Information requirements, data collection methods, and precision all affect sampling costs. Total sampling costs must be identified during pre-sample planning to determine the funding required to implement the sampling plan. If adequate funding is not available, then a decision to modify or discontinue the sample is needed.

Trade-Offs

Once these initial decisions have been made, trade-offs between some or all of these decisions may be necessary. For example, limited funding may constrain the precision of the estimate. Generally, the lower the funding, the less precise is the estimate. Funding may also constrain the sample method used, because some methods are much more costly than others. Funding may also constrain the amount of information about operations that can be obtained and the number of periods for which operations can be estimated. Information requirements may also require trade-offs. For instance, it may be more important to know something about the type of operations, than to have a more precise estimate of total annual operations.

It is important that the pre-sample decisions be made and any necessary trade-offs reconciled before the sample plan is developed. Careful pre-sample planning will help avoid time delays and costly mistakes during the development and implementation of the sampling plan.

Figure 1. Summary of Operations Sampling and Estimating Process



2. DEVELOPING A SAMPLING PLAN

The two main objectives of a sampling plan for aircraft operations are to ensure representative time periods are sampled and a sufficient number of periods are sampled to provide an operations estimate with the required degree of precision. This section describes a sampling plan that meets these objectives and can be applied in a variety of situations.

Define Time Periods to be Sampled

Aircraft operations are known to vary according to the weather and the day of the week.[3] Operations increase during good weather (visual flight rules conditions) and decrease during bad weather (instrument flight rules conditions). Operations generally increase on the weekends if operations are predominately due to recreational or pleasure flying. On the other hand, operations will be greater on weekdays if they are largely due to business flying or air taxi services.

To capture the daily variation in operations due to type of flying, the sample must be drawn on different days of the week. The easiest and least costly way to accomplish this is to sample a cluster of seven consecutive days; that is, sample an entire week. All operations on each of the seven days sampled are counted.

In order to capture the variation in operations due to the weather, at least one week must be sampled in each season throughout the year. This is done by stratifying (i.e., dividing) the year into two or more seasons based on weather patterns. The seasons do not need to be of equal length. For much of the nation calendar quarters serve very well as seasonal divisions. At least two weeks must be sampled per season if operations estimates are to be made for each season as well as for the year.

Determine Sample Size

The size of the sample, in this case, the total number of weeks sampled, will depend on a trade-off between cost and the desired precision of the estimate. Generally, larger samples are more precise, but also more costly. Before going into detail, there are three rules of thumb for determining sample size:

1. The greater the precision desired in the estimate, the larger the sample size needed;
2. The lower the activity at an airport, the greater the variation in operations among days of the week and seasons; and
3. The greater the variation in operations among days of the week and seasons, the larger the sample size needed to make an estimate with a given degree of precision.

These three considerations are incorporated in Table 1. The table can be used to determine sample size based on the desired precision of the operations estimate and a preliminary estimate of total operations. Once the required sample size is determined, costs of collecting the sample can be estimated. If adequate funding is not available, the size and accuracy of the sample will have to be reduced.

Table 1 provides an approximation of the sample size needed when little is known about the airport to be sampled, except a preliminary estimate of total activity. A preliminary estimate of activity can be made based on the airport master plan, FAA Airport Master Records (5010-1 forms), or the estimates of the fixed base operator or manager of the airport. The table allows a more efficient use of funds by tailoring the sample size to the estimated activity level of the airport and the likely variation in operations. The table helps avoid expensive oversampling, whereby more data is collected than needed for a satisfactory estimate. It also helps avoid undersampling, resulting in an estimate with a larger sampling error than is acceptable.

If seasonal as well as annual operations estimates are required, a sample larger than needed to achieve the desired precision may be necessary. For example, if an airport with about 30,000 operations is to be sampled and a 20 percent sampling error is desired, Table 1 indicates a sample size of six weeks is adequate. However, if estimates of operations in each of four seasons are required in addition to the annual estimate, at least two weeks must be sampled in each season. Therefore, a sample size of eight weeks is needed. In this case the larger sample size was needed for the seasonal estimate requirement rather than for the precision requirement.

Once the total sample size is determined, it must be divided among seasons. A good rule to follow is to allocate the total sample size among seasons based on the relative size of each season. For example, if there are two seasons, one three months long (one-fourth of the year) and the other nine months long (three-fourths of the year), then one-fourth of the total sample size would be drawn from the first season and three-fourths of the sample would be drawn from the second season. If the seasons are of equal length, then the total sample size would be divided equally among the seasons. These are called seasonally proportional samples.

In some cases the sample may not be seasonally proportional. Sample weeks divided proportionally among seasons may result in only one week being sampled in a season. However, if a seasonal estimate is desired, at least two weeks must be sampled. The added week will result in

[3]Variation in aircraft operations by weather and day of the week has been observed during aircraft operations counts in Florida, Idaho, Michigan, Oregon, Texas, and Washington.

Table 1. Approximate Percent Sampling Error in Annual Operations Estimate at 95 Percent Confidence Level by Size of Airport and Size of Sample

Approximate Annual Operations at Airport Being Sampled	Number of Weeks Sampled Per Year								
	4	5	6	7	8	9	10	11	12
Less Than 900	± 54%	± 48%	± 44%	± 40%	± 37%	± 34%	± 32%	± 30%	± 29%
900 - 2,399	51	45	41	37	34	32	30	28	27
2,400 - 4,399	47	42	38	35	32	30	28	26	25
4,400 - 7,199	44	39	35	32	30	27	26	24	23
7,200 - 10,499	40	35	32	29	27	25	24	22	21
10,500 - 14,599	36	32	29	27	25	23	21	20	19
14,600 - 19,199	33	29	26	24	22	21	19	18	17
19,200 - 24,599	29	26	23	21	20	18	17	16	15
24,600 - 30,499	25	23	20	19	17	16	15	14	13
30,500 And Over	22	19	17	16	15	14	13	12	12

a larger sample in that season. A non-proportional sample also results if a season is intentionally sampled more heavily to obtain a more precise estimate of operations for that particular season.

Randomly Choose Sample Weeks

Assuming the sample is seasonally proportional, weeks can be sampled at equal intervals throughout the year. One week must be randomly chosen and the others selected at equal intervals around the randomly chosen week.

If the sample is not proportional, then it will be necessary to select sample weeks independently for each season. in this case one week in each season is randomly chosen and additional weeks chosen are spaced equally throughout each season.

Table 2, "Random Numbers from 1 to 52", may be used to select a week at random. First, number all weeks in the year or the season. For example, to randomly choose one week out of the year, weeks are numbered from 1 to 52. Weeks can be numbered starting with the first week in January or with the first week in the first season to be sampled. To randomly choose one week out of a three-month season, weeks are numbered from 1 to 13, starting with the first week in the season.

To use Table 2, arbitrarily choose any column and any row in the table. Where they intersect is a random number between 1 and 52. This number corresponds to one of the weeks numbered above and serves to randomly choose that week for the sample. For example, if column number 9 and row number 23 are arbitrarily chosen, the number where they intersect is 35. Therefore, week number 35 is chosen for the sample. It should be noted that this week will not necessarily be the first week in which aircraft operations are counted. The first week counted will depend on when the sample is scheduled to begin.

The week randomly chosen from Table 2 serves as a starting point for choosing the additional weeks to be included in the sample. In a seasonally proportional sample all additional weeks are sampled at equal intervals throughout the year. The sampling interval is determined by dividing the total number of weeks in the year (52) by the sample size. For example, if an eight-week sample is planned, the interval will be 6.5 weeks. If week 35 is randomly chosen from Table 2, then weeks 3, 9, 16, 22, 29, 42, and 48 would also be included in the sample. If a week chosen does not fall entirely within one season, it should be assigned to the season in which four of the seven days fall. For a proportional sample, this process ensures the sample weeks are randomly chosen and are evenly spaced throughout the year.

If the sample is not seasonally proportional, then one week in each season must be randomly chosen. Additional weeks are chosen at equal intervals throughout the season. The interval is established separately for each season by dividing the number of weeks in the season by the sample size for the season.

When randomly choosing a week in a season the random number picked from Table 2 may not match any of the week numbers in the season. For example, in the January to March winter season, the weeks are numbered from 1 to 13. However, number 46 may be picked from Table 2. In such a case, move up or down the same column, or left or right along the same row until a usable number is reached, in this case a number from 1 to 13. If, in moving through the table, the edge is reached (top, bottom, left, or right) jump to the opposite edge of the table and continue moving in the same direction until a usable number is reached.

In some cases a number of airports will be counted during the same period. If one individual or mechanical counter is used, no two airports can be sampled simultaneously. Therefore, it is necessary to schedule sample weeks that do not overlap. This is done by choosing sample weeks for the first airport as discussed above. Once chosen, these weeks are no longer available to be sampled. Sample weeks for the second airport are chosen in the same manner from the remaining weeks. This is called sampling without replacement. The sampling process is repeated with fewer weeks available for each successive airport.

After the sampling plan has been developed it should be reviewed to ensure it can be implemented as intended. This is particularly important when sample weeks have been chosen for several airports without replacement. The sample plan should be checked to ensure:

1. The number of weeks sampled are sufficient for the desired precision and for the periods being estimated;
2. The required number of weeks are sampled in each season; and
3. Each sampled week falls entirely within one season, or if not, is assigned to the season in which four of the seven days fall.

Example

The above sampling plan was applied to Tri-City State Airport in 1983-84. The year was divided into four seasons--winter, spring, summer, and fall--which correspond to the four calendar quarters. An estimate of annual operations and seasonal operations was required.

Table 1 was used to determine the sample size for Tri-City State Airport. Little was known about the level of activity at the airport, but for planning purposes it was assumed to be about 4,500 operations. A sampling error of 30 percent was considered tolerable for the estimate of annual operations. Given this information, Table 1 indicates a sample size of eight weeks would provide a sampling error of 30 percent and would therefore be adequate for the airport. The eight-week sample was equally divided among the four seasons, resulting in a seasonally proportional sample with two weeks sampled per season. At least two weeks per season are necessary to make seasonal operations estimates of a known precision

Table 2. Random Numbers From 1 to 52

ROW	COLUMN 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	3	11	44	21	37	37	50	24	52	46	19	6	27	5	49	44	30	50	30	41	29	10	6	5	32
2	49	6	9	51	26	6	7	44	2	26	47	46	11	18	9	49	14	1	39	24	2	50	33	10	20
3	40	8	51	36	15	25	20	50	26	14	4	3	39	3	32	11	39	37	25	23	21	25	12	5	29
4	31	26	38	43	25	21	11	34	6	40	39	30	39	14	48	9	35	29	19	10	44	25	10	44	29
5	33	45	29	28	13	34	41	49	30	2	49	30	50	27	28	30	32	26	24	12	15	39	48	46	50
6	48	46	48	36	37	9	26	33	17	15	44	28	29	30	25	38	5	45	30	35	43	45	45	20	24
7	24	32	28	39	39	40	48	32	23	6	34	51	8	2	45	2	13	17	41	43	49	15	9	24	13
8	24	26	49	10	32	51	28	16	51	13	33	37	31	9	35	31	27	44	28	24	51	46	28	9	11
9	41	44	4	40	10	5	45	29	27	7	9	43	30	51	40	41	39	25	2	50	29	36	9	38	50
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11	2	46	6	36	8	35	38	23	4	22	52	14	30	9	43	27	35	25	42	34	32	39	2	23	23
12	39	32	1	30	22	16	8	9	39	49	2	33	32	3	40	12	24	40	27	11	33	5	41	6	22
13	36	18	48	23	15	45	37	19	45	51	8	52	35	52	3	14	16	22	44	13	47	14	21	3	35
14	35	4	18	27	6	5	29	33	39	45	27	15	2	31	18	37	11	46	31	27	43	18	31	29	2
15	8	32	25	18	43	46	44	11	28	21	28	36	21	11	30	35	45	14	38	51	21	30	43	40	13
16	26	44	30	47	12	11	16	51	7	51	42	46	5	32	49	8	18	36	11	49	2	30	15	24	14
17	22	12	30	19	5	13	40	23	39	30	36	2	45	8	50	31	45	41	3	7	19	7	27	3	34
18	32	39	6	44	8	16	26	18	32	33	18	23	26	9	25	25	26	41	13	16	40	44	10	31	45
19	48	42	31	15	20	41	12	17	49	45	34	10	9	17	28	18	14	29	50	43	13	5	19	23	21
20	26	20	41	22	23	42	47	14	21	51	22	34	11	16	5	42	7	25	37	50	25	12	2	15	21
21	47	44	49	4	47	43	45	42	4	12	37	15	15	13	48	24	17	44	17	16	49	3	38	5	44
22	20	39	4	37	35	31	35	31	32	18	33	36	25	33	28	28	22	41	51	47	27	48	49	25	15
23	27	25	17	36	13	14	23	15	35	30	25	30	15	26	25	26	33	19	25	31	15	22	51	7	46
24	14	36	39	18	13	26	43	25	26	38	47	50	33	6	42	2	45	4	26	26	22	10	15	7	11
25	6	38	28	32	42	23	18	8	40	20	22	3	28	47	32	26	30	50	37	27	38	41	12	10	11
26	28	28	19	21	7	15	26	29	45	12	30	27	45	34	2	21	11	28	23	46	20	21	52	21	26
27	18	29	21	21	40	6	36	9	44	30	50	28	33	48	49	15	16	12	37	15	20	38	51	18	9
28	46	47	24	26	46	46	26	45	44	16	10	20	33	26	12	50	39	44	22	46	30	25	36	43	40
29	8	48	15	23	3	20	49	14	10	37	33	22	44	18	25	43	38	4	41	7	36	49	30	46	9
30	3	46	47	29	9	4	45	36	21	11	34	10	11	31	40	18	6	36	13	8	41	21	15	8	20

Examples of How To Fill Out Forms 1 through 4

The following figures illustrate how Forms 1 through 4 are filled out, using sample operations data from Tri-City State Airport (see Figure 2 for a review of the Tri-City State Airport sampling plan). Figures 4 and 5 each show how Form 1, Sample Data, is filled out for one week of operations data. Two figures are shown because at least two weeks of data are needed to illustrate how Forms 3 and 4 are filled out. A total of eight Sample Data Forms, one for each of the eight weeks sampled, are needed for Tri-City State Airport.

Figures 6 and 7 each show how Form 2, Weekly Data, is filled out. Two figures are shown because a separate Form 2 is needed for each Form 1 used. The boxes at the top of each of the eight Form 2's used for Tri-City State Airport are filled out the same as the eight Form 1's.

Figure 8 shows how Form 3, Seasonal Data, is calculated. A separate Form 3 is completed for each season. The Tri-City State Airport sampling plan requires four Seasonal Data Forms, one of which is shown in Figure 8. Calculations from Figure 8 and from the other three Seasonal Data Forms (not shown) are transferred to Form 4 (Figure 9).

Figure 9 shows how the numbers and calculations from each of the four seasons are combined on Form 4 to estimate annual operations and the precision of the estimate.

FORM 4
ANNUAL ESTIMATES

Airport Name	
Sample Period	
From	To

SEASON	(A) TOTAL DAYS D	(B) D^2	(C) SAMPLED DAYS d	(D) $\frac{D^2}{d}$	(E) $\frac{d}{D}$	(F) $1 - \frac{d}{D}$
1						
2						
3						
4						

SEASON	(G) TOTAL DAYS D	(H) AVERAGE (FORM 3, (C))	(I) TOTAL (G) x (H)
1			
2			
3			
4			
		ANNUAL OPERATIONS	(J) Sum of Col. (I)

SEASON	(K) FROM FORM 3, (V)	(L) $\frac{D^2}{d}$	(M) COLUMN (K) x COLUMN (L)	(N) $1 - \frac{d}{D}$	(O) COLUMN (M) x COLUMN (N)
1					
2					
3					
4					

VARIANCE OF OPERATIONS (P) Sum of Col. (O)

(Q) $\sqrt{(P)}$

t-VALUE FROM CHART (R)

95% CONFIDENCE INTERVAL (S) ± (Q) x (R)

PERCENT SAMPLING ERROR (T) ± ((S) ÷ (J)) x 100

t-VALUE CHART

Find Lowest Value of d from Column (C)

If d-1,	then	t
3		3.182
4		2.776
5		2.571
6		2.447
7		2.365
8		2.306
9		2.262
10		2.228
11		2.201
12		2.179
13		2.160
14		2.145
15		2.131
16		2.120
17		2.110
18		2.101
19		2.093
20		2.086
30		2.042
40		2.021
50		2.009
60		2.000
80		1.990

INSTRUCTIONS FOR FORM 4
ANNUAL ESTIMATES

The purpose of Form 4 is to expand the sample data to estimate total annual operations and to calculate measures of precision of the estimate of annual operations, including the confidence interval and the percent sampling error.

In the boxes at the top of Form 4 fill in the name of the airport sampled and the period of the sample.

Column (A)	Fill in the total number of days, D, in each season on the lines in column (A). Use the actual number of calendar days, not number of weeks, N, times 7 days. (If data is not stratified by season, only one line will be used.)
Column (B)	Square each value of D and enter the answer in column (B).
Column (C)	Fill in the number of days sampled, d, in each season on the lines in column (C).
Column (D)	For each season divide D^2 in column (B) by d in column (C) and enter the answer in column (D).
Column (E)	For each season divide d in column (C) by D in column (A) and enter the answer in column (E).
Column (F)	Subtract $\frac{d}{D}$ in column (E) from 1 and enter the answer in column (F).
Column (G)	Transfer the value of D for each season from column (A) to the appropriate line in column (G).
Column (H)	Fill in the average daily operations for each season on the lines in column (H). Average daily operations are obtained from Form 3, box (C).
Column (I)	For each season, multiply D in column (G) by average daily operations in column (H). Enter the answer on the appropriate line in column (I).
Box (J)	Add the values in column (I) and enter the answer, annual operations, in box (J).
Column (K)	Fill in the value from Form 3, box (V) for each season on the appropriate line in column (K).
Column (L)	For each season, transfer the values for $\frac{D^2}{d}$ from column (D) to column (L).
Column (M)	For each season multiply the value in column (K) by $\frac{D^2}{d}$ in column (L). Enter the answer in column (M).
Column (N)	For each season transfer the value $1 - \frac{d}{D}$ from column (F) to column (N).
Column (O)	For each season multiply the value in column (M) by $1 - \frac{d}{D}$ in column (N) and enter the answer in column (O). This value is the variance of operations in each season.
Box (P)	Add the values in column (O). Enter the answer, the variance of estimated annual operations, in box (P).
Box (Q)	Take the square root of the value in box (P) and enter the answer in box (Q).
Box (R)	Find the appropriate t-value from the chart, based on the value (d-1). (Find d from column (C), then subtract 1.) Use the lowest value of d in column (C). Enter the t-value in box (R).
Box (S)	Multiply the value in box (Q) by the t-value in box (R). Enter the answer in box (S). This is the 95 percent confidence interval or range of the estimated operations. It is a measure of the precision of the annual operations estimate.
Box (T)	Divide the value in box (S) by the value in box (J) and multiply by 100. Enter the answer in box (T). This is the percent sampling error, which is also a measure of the precision of the annual operations estimate.

FORM 3
SEASONAL DATA

Airport Name
Season No.

TOTAL WEEKS IN SEASON	N
WEEKS SAMPLED IN SEASON	n
DAYS IN WEEK	M

	(A)	(D)	(E)	(K)
WEEK	AVERAGE DAILY OPERATIONS (FORM 2,(D))	COLUMN (A)-(C)	COLUMN (D) SQUARED	FROM FORM 2, (G)
1				
2				
3				
4				

Box	Contents
(B)	Sum Col. (A)
(F)	Sum Col. (E)
(L)	Sum Col. (K)
(G)	n-1
(P)	n x (M-1)
(H)	(F)÷(G)
(Q)	(L)÷(P)
(I)	(N-1)
(R)	N x (M-1)
(J)	(H) x (I)
(S)	(Q) x (R)
(T)	(J) + (S)
(U)	(NxM) - 1
(V)	T÷(U)

AVERAGE DAILY OPERATIONS FOR SEASON (C): (B)÷n

Use to Calculate Col. (D)

Transfer to Form 4, Col. (H)

Transfer to Form 4, Col. (K)

Complete a separate Seasonal Data Form for each season. For example, if the year is divided into four seasons, then a total of four Seasonal Data Forms are completed. More rows may be added to Form 3 if more than four weeks are sampled in the season.

INSTRUCTIONS FOR FORM 3
SEASONAL DATA

The purpose of Form 3 is to find average daily operations for each season and to calculate numbers that will be used on Form 4. If data is not stratified into seasons it will still be necessary to complete this form, treating all data as though they were from a single year-long season.

In the boxes at the top of Form 3 fill in the name of the airport sampled. Fill in the number of the season from which the sample data were collected. Also fill in the season size, N (total number of weeks in the season), the sample size, n (number of weeks sampled in the season), and the week size, M (normally 7).

(Note: Form 3 assumes a cluster of 7 days (one week) is sampled, and therefore N, n, and M are based on weeks (see Figure 8). If a cluster of days less than one week or greater than one week is sampled, then N will be the total number of clusters in the season; n will be the number of clusters sampled in the season, and M will be the number of days in the cluster. For example, if two 2-week clusters are sampled in a three-month season, then N is 6.5, n is 2, and M is 14.)

Column (A)	Fill in the average daily operations per week on the lines in column (A). Average daily operations per week are transferred from Form 2, box (D). Column (A) may have 2 or more lines depending on the number of weeks sampled.
Box (B)	Add the values in column (A) and enter the answer in box (B).
Box (C)	Divide the value in box (B) by n (find n in box at top of Form 3). Enter the answer in box (C). This number will be used in column (D) and transferred to Form 4, column (H).
Column (D)	Subtract the value in box (C) from the value on line 1 in column (A). Enter the answer on line 1 in column (D). Repeat this step for each value in column (A).
Column (E)	Square each value in column (D) and enter the answer (always a positive number) in column (E).
Box (F)	Add the values in column (E) and enter the answer in box (F).
Box (G)	Subtract 1 from n (find n in box at top of Form 3) and enter the answer in box (G).
Box (H)	Divide the value in box (F) by the value in box (G) and enter the answer in box (H).
Box (I)	Subtract 1 from N (find N in box at top of Form 3) and enter the answer in box (I).
Box (J)	Multiply the value in box (H) by the value in box (I). Enter the answer in box (J).
Column (K)	Enter the value from Form 2, box (G) for each week on the appropriate line in column (K).
Box (L)	Add the values in column (K) and enter the answer in box (L).
Box (P)	Subtract 1 from M (find M in box at top of Form 3). Multiply the value (M-1) by n and enter the answer in box (P).
Box (Q)	Divide the value in box (L) by the value in box (P) and enter the answer in box (Q).
Box (R)	Subtract 1 from M. Multiply the value (M-1) by N and enter the answer in box (R).
Box (S)	Multiply the value in box (Q) by the value in box (R) and enter the answer in box (S).
Box (T)	Add the values in box (J) and box (S) and enter the answer in box (T).
Box (U)	Multiply N times M and then subtract 1. Enter the answer in box (U).
Box (V)	Divide the value in box (T) by the value in box (U) and enter the answer in box (V). This value is also transferred to Form 4, column (K).

FORM 2
WEEKLY DATA

Airport Name	
Season No	Week No

	(A)	(B)	(E)	(F)
DAY	DATE	DAILY OPERATIONS	COLUMN (B)-(D)	COLUMN (E) SQUARED
1				
2				
3				
4				
5				
6				
7				

TOTAL WEEKLY OPERATIONS

(C)

Sum of Col. (B)

(G)

Sum of Col. (F)

Transfer (G) to Form 3. Col (K)

AVERAGE DAILY OPERATIONS

(D)

(C)÷No. of Days

Use in Col (E)

Transfer (D) to Form 3 Col (A)

Complete a separate Weekly Data Form for each week sampled in each season For example if three weeks are sampled per season and the year is divided into four seasons then a total of 12 Weekly Data Forms are completed

INSTRUCTIONS FOR FORM 2
WEEKLY DATA

The purpose of Form 2 is to calculate total operations and average daily operations for each week, and other numbers that will be used on Form 3.

In the boxes at the top of Form 2 fill in the name of the airport sampled and the season number and week number from which the data were collected.

Column (A)	Fill in the date of each day sampled on the lines in column (A).
Column (B)	Fill in the number of operations counted on each date on the lines in column (B). Operations for each date are obtained from the bottom row of Form 1.
Box (C)	Add the values in column (B). Enter the answer, total weekly operations, in box (C).
Box (D)	Divide the value in box (C) by the number of days counted in the week (normally 7). Enter the answer, average daily operations, in box (D). This number will be used in column (E) and transferred to Form 3, column (A).
Column (E)	Subtract the value in box (D) from the value on line 1 in column (B). Enter the answer on line 1 of column (E). Repeat this step, subtracting (D) from each value in column (B).
Column (F)	Square each value in column (E) and enter the answers in column (F). (All squared numbers will be positive.)
Box (G)	Add the values in column (F). Enter the answer in box (G). This number will be transferred to Form 3, column (K).

FORM 1
SAMPLE DATA

Airport Name	
Season No.	Week No.

DAY:	1	2	3	4	5	6	7
TIME OF DAY	Date	Date	Date	Date	Date	Date	Date
MID NIGHT							
01:00							
02:00							
03:00							
04:00							
05:00							
06:00							
07:00							
08:00							
09:00							
10:00							
11:00							
12:00							
13:00							
14:00							
15:00							
16:00							
17:00							
18:00							
19:00							
20:00							
21:00							
22:00							
23:00							
TOTALS							

INSTRUCTIONS FOR FORM 1
SAMPLE DATA

The purpose of Form 1 is to serve as a worksheet to tally or tabulate the sample data and to obtain total daily operations.

In the boxes at the top of the form fill in the name of the airport sampled and the season number and week number from which the data were collected. Weeks sampled are numbered consecutively throughout the year. Fill in the date of each of the seven days sampled.

Day 1 — Tabulate the number of operations counted during each hour in Day 1. Add the hourly operations. Enter the answer in the total box at the end of the column for Day 1.

Day 2-7 — Repeat the tabulation of hourly operations for each day. Add each column of hourly operations to obtain total operations for each day. Daily operations will be transferred to Form 2, Weekly Data, column (B).

4. ORGANIZING SAMPLE DATA AND ESTIMATING OPERATIONS

As the sample data is collected, it is important to have a systematic means to organize and tabulate the sample data and to estimate operations. Forms have been developed to guide the user step-by-step through a series of calculations that end in an estimate of annual operations and a measure of the precision of the estimate of annual operations. Figure 3 summarizes the calculations and shows their relationship to one another. Estimating equations are presented in Appendix B, Statistical Derivation of Estimating Procedures, for users who prefer to make the calculations using equations rather than the forms.

The first step is to tally weekly operations. Average daily operations for each week can then be calculated. These are combined to find average daily operations for each season. The season averages are expanded to total operations in each season. The season totals are then added to obtain an estimate of total annual operations.

Daily, weekly, and average daily operations for each week and for each season are all used to calculate the variation in operations. The variation in operations provides a way to determine the precision or range of the estimate of annual operations. Precision can be expressed as a confidence interval (e.g., plus or minus 1,000 operations) The confidence interval is an estimated range in which one can be 95 percent confident that the true number of operations will fall.[4] Precision can also be expressed as a percent sampling error, which is the confidence interval divided by estimated operations (e.g., the confidence interval of 1,000 operations divided by the annual estimate of 10,000 operations equals a sampling error of plus or minus 10 percent of the estimated annual operations).

The first section contains a set of standard forms and instructions that provide a step-by-step format for making operations estimates. The forms can be photocopied and used directly, or they can be computerized with standard spread sheet programs.

The second section contains Figures 4 through 9, which illustrate how to fill out each form, using sample data from Tri-City State Airport.

If sample data are incomplete so that forms cannot be completed as described, Appendix A, Corrections for Loss of Sample Data, describes alternate procedures for calculation of annual operations and the sampling error.

Sampling and Estimating Forms

The following forms and their instructions are presented in this section:

Form 1, Sample Data, for tabulating and summarizing the daily sample data;[5]

Form 2, Weekly Data, for tallying total weekly operations and estimating average daily operations;

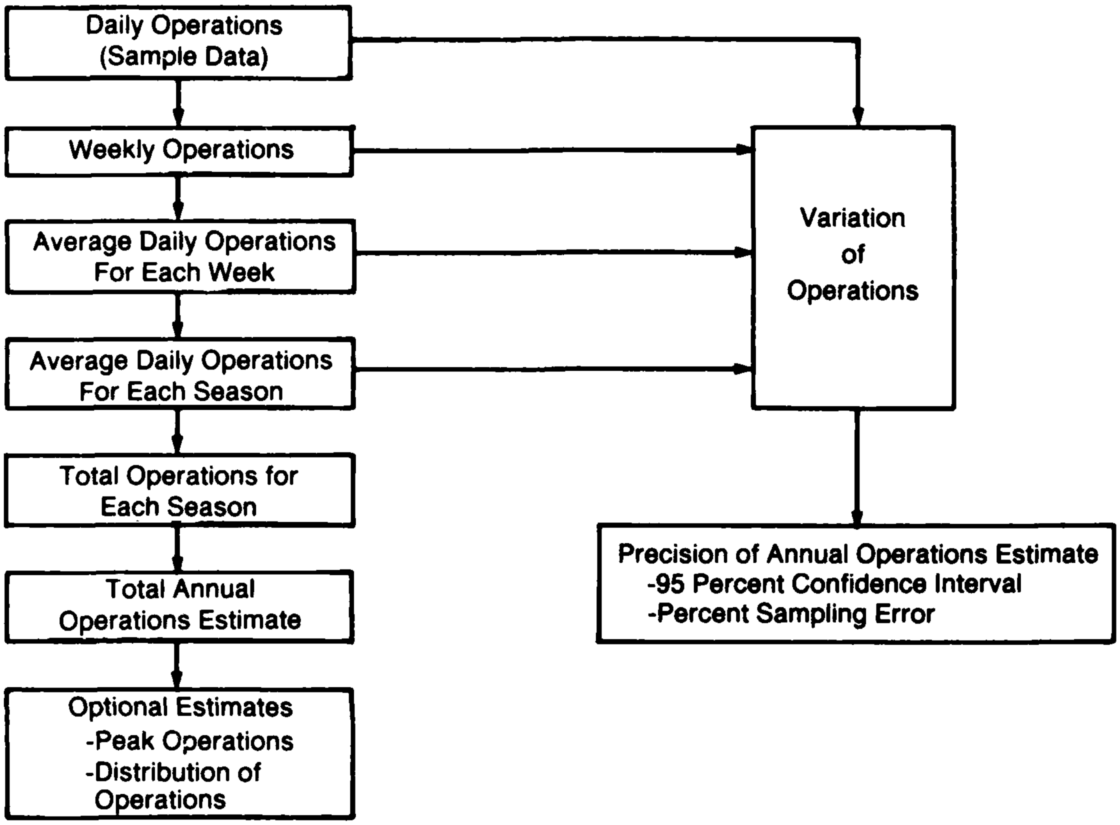
Form 3, Seasonal Data, for estimating average daily operations and the variance of the estimate for each season; and

Form 4, Annual Estimates, for estimating total annual operations and the 95 percent confidence interval and sampling error of the estimate of total annual operations.

[4]The 95 percent refers to the confidence level or degree of certainty that the true number of operations will fall within the confidence interval. Calculations in this handbook are based on a 95 percent confidence level.

[5]Form 1 is one example of possible sample data forms that could be used. The format of the data form will vary according to the type of information collected about aircraft operations. The minimum requirement for Form 1 is to provide a tally of total operations for each day counted.

Figure 3. Steps in Estimating Annual Operations and the Precision of the Annual Operations Estimate



3. COLLECTING SAMPLE DATA

There are a number of different methods to collect sample operations data. Different counting methods, including their relative pros and cons, are discussed in Chapter 6.

Regardless of the counting method used, there are two primary concerns in collecting sample data: that operations counts are accurate and that the schedule developed as part of the sampling plan is followed. Statistical sampling is a proven process, but it is only as reliable as the sample data collected.

To ensure accurate data, it is important that counting procedures are applied correctly and the results interpreted within the limitations of the technique used. For example, an acoustical counter normally only records departures, which must be doubled to measure operations. If the counter is incorrectly positioned it may not record all departures. Many procedures using pneumatic tubes actually record activity on taxiways. The data must then be accurately related to operations to obtain meaningful counts. Visual observation directly counts operations and is therefore less subject to errors in interpretation. However, procedures for visual counts must be established and followed to ensure that the counts are consistent and complete. If information about each operation is being gathered, such as local or itinerant flight, the characteristics must be defined and the observer trained in how to classify each operation.

In addition to the correct application of counting methods, it is extremely important that sampling plans be followed and that counts be conducted as scheduled. Any deviation from the plan may reduce accuracy by interfering with the random choice of counting periods, or by reducing the sample size. If the sample is not random, then biases that statistical samples are designed to eliminate may be reintroduced. If particular types of weather conditions, or other factors affecting aviation activity are favored in collecting the sample data, then the estimate may not accurately reflect activity at the airport.

Reducing the sample size, either by reducing the number of days counted in a week or by reducing the number of weeks counted in a season, will reduce precision as reflected by an increase in the sampling error. In some cases schedule changes or loss of data can be dealt with, as described in Appendix A. However, given the seasonal nature of general aviation activity, if at least one week is not sampled in each season, then no reliable annual operations estimate can be made. In such a case the estimate may be biased upward if a low season was missed, or may be biased downward if a busy season was missed.

Table 3. Randomly Chosen Weeks for Tri-City State Airport

6.5 Week Intervals	Sample Week Chosen (Rounded)	Week Renumbered In Order of Count
5*	5	1
11.5	12	2
18.0	18	3
24.5	25	4
31.0	31	5
37.5	38	6
44.0	44	7
50.5	51	8

*5 chosen from Random Numbers Table

It should be noted that Table 1 provides only an approximation of sampling error based on a preliminary estimate of airport activity and sample size. The actual sampling error calculated from the sample data may differ. For example, the eight-week sample for Tri-City State Airport resulted in an actual sampling error of 28.6 percent, rather than the 30 percent indicated by the table.

Figure 2 illustrates the sampling plan for Tri-City State Airport. The counting program started in the third quarter (summer), which was numbered season 1. The first of the eight weeks to be sampled was randomly chosen using a random numbers table. First, all weeks in the year were numbered consecutively from 1 to 52, starting with the first week in season 1 (July 1-7, 1983). Then, starting at an arbitrary place in the random numbers table, the number 5 was picked. Therefore week number five (July 29-August 4, 1983) was the first sample week chosen.

Since a proportional sample was planned, additional weeks were sampled at equal intervals throughout the year. The sampling interval was determined based on the total number of weeks in the year (52) divided by the sample size (8), which equals 6.5 weeks. Therefore, starting with week number 5, successive weeks were chosen in multiples of 6.5 (Table 3). Week numbers were then rounded to the nearest whole number. After all eight weeks were chosen, they were renumbered from 1 to 8 in the order that they will actually be counted.

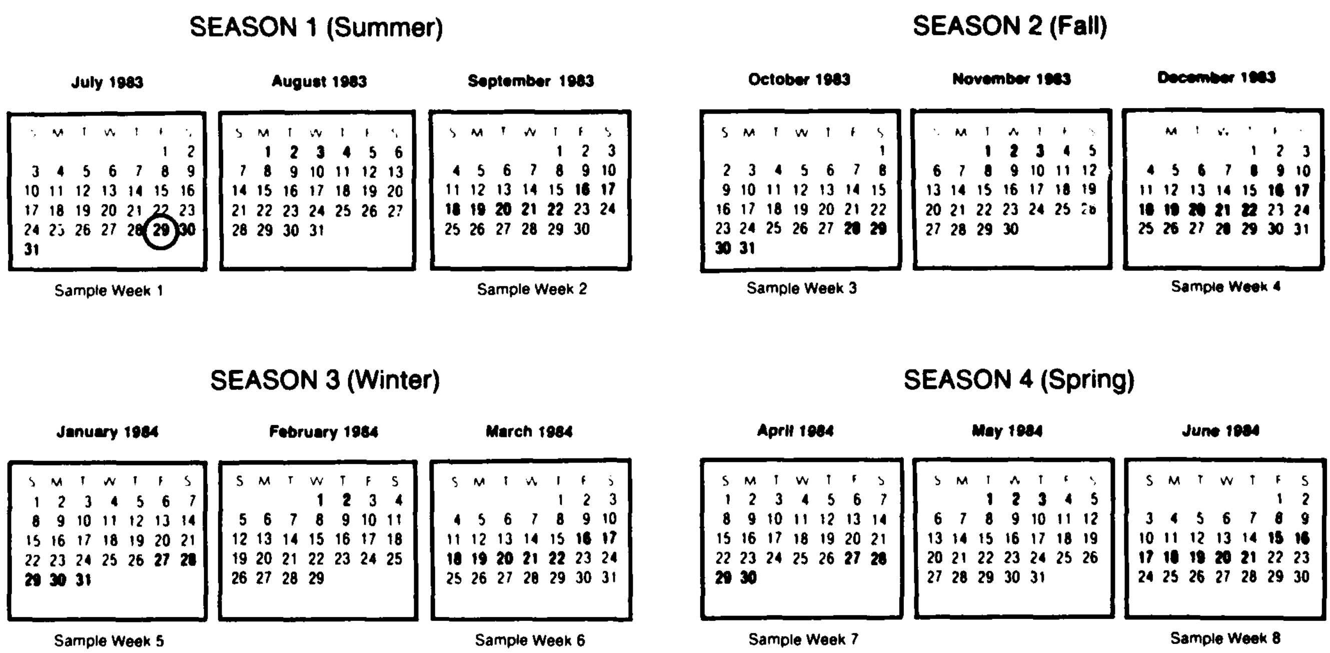
Note that the first week randomly chose from Table 2 is not necessarily the first week to be counted. If week number 20 had been randomly chosen from the table, then in choosing additional weeks it would have been necessary to "wrap around" from June in season 4 to July in season 1 to continue choosing weeks until eight weeks had been picked (Figure 2). In such a case, the eight weeks chosen would be renumbered from 1 to 8 starting in July to reflect the order in which they will actually be counted.

Figure 2. Sampling Plan for Tri-City State Airport

Seasons = 4, each 13 weeks long (correspond to calendar quarters)

Sample Size = 8 weeks, 2 weeks in each season (seasonally proportional)

Sample Interval = 6.5 weeks ($52 \div 8 = 6.5$)



○ First week randomly chosen

Additional weeks sampled at equal intervals

Figure 4. Example of Form 1, Sample Data
For Week Number 1

FORM 1
SAMPLE DATA

Airport Name	Tri-City State
Season No 1	Week No 1

DAY:	1	2	3	4	5	6	7
TIME OF DAY	Date 7/29/83	Date 7/30/83	Date 7/31/83	Date 8/1/83	Date 8/2/83	Date 8/3/83	Date 8/4/83
MID NIGHT							
01:00							
02:00							
03:00							
04:00							
05:00							
06:00							
07:00							2
08:00							4
09:00							
10:00	2			2	4		
11:00			2		2		
12:00	6		2	2	2	2	2
13:00	2				2	2	
14:00	10		2	2			2
15:00	2		2				2
16:00	6	4					
17:00		2					2
18:00							
19:00							
20:00							
21:00							
22:00							
23:00							
TOTALS	28	6	8	6	10	4	14

Figure 5. Example of Form 1, Sample Data For Week Number 2

FORM 1
SAMPLE DATA

Airport Name	Tri - City State
Season No 1	Week No 2

DAY:	1	2	3	4	5	6	7
TIME OF DAY	Date 9/16/83	Date 9/17/83	Date 9/18/83	Date 9/19/83	Date 9/20/83	Date 9/21/83	Date 9/22/83
MID NIGHT							
01:00							
02:00							
03:00							
04:00							
05:00							
06:00							
07:00							
08:00							
09:00				2			
10:00			2				
11:00							
12:00	4			10			
13:00	2	2					6
14:00							
15:00						4	
16:00							
17:00						2	
18:00							
19:00	2						
20:00							
21:00							
22:00							
23:00							
TOTALS	8	2	2	12	0	6	6

Figure 6. Example of Form 2, Weekly Data
For Week Number 1

FORM 2
WEEKLY DATA

Airport Name	TRI-CITY STATE
Season No 1	Week No 1

	(A)	(B)	(E)	(F)
DAY	DATE	DAILY OPERATIONS	COLUMN (B)-(D)	COLUMN (E) SQUARED
1	7/29/83	28	17.14	293.78
2	7/30/83	6	- 4.86	23.62
3	7/31/83	8	- 2.86	8.18
4	8/1/83	6	- 4.86	23.62
5	8/2/83	10	- .86	.74
6	8/3/83	4	- 6.86	47.06
7	8/4/83	14	3.14	9.86

TOTAL WEEKLY OPERATIONS (C) 76 — Sum of Col. (B)

(G) 406.86 — Sum of Col. (F)

AVERAGE DAILY OPERATIONS (D) 10.86 — (C) ÷ No. of Days

Use in Col. (E)

Transfer (G) to Form 3 Col. (K)

Transfer (D) to Form 3 Col. (A)

Complete a separate Weekly Data Form for each week sampled in each season. For example, if three weeks are sampled per season and the year is divided into four seasons, then a total of 12 Weekly Data Forms are completed.

Figure 7. Example of Form 2, Weekly Data
For Week Number 2

FORM 2
WEEKLY DATA

Airport Name	TRI - CITY STATE
Season No 1	Week No 2

	(A)	(B)	(E)	(F)
DAY	DATE	DAILY OPERATIONS	COLUMN (B)-(D)	COLUMN (E) SQUARED
1	9/16/83	8	-2.86	8.18
2	9/17/83	2	- 3.14	9.86
3	9/18/83	2	- 3.14	9.86
4	9/19/83	12	6.86	47.06
5	9/20/83	0	-5.14	26.42
6	9/21/83	6	.86	.74
7	9/22/83	6	.86	.74

TOTAL WEEKLY OPERATIONS (C) 36
[illegible]

(G) 102.86
[illegible]

Use in Col (E)

Transfer (G) to Form 3 Col (K)

AVERAGE DAILY OPERATIONS (D) 5.14
[illegible]

Transfer (D) to Form 3 Col (A)

Complete a separate Weekly Data Form for each week sampled in each season. For example, if three weeks are sampled per season and the year is divided into four seasons, then a total of 12 Weekly Data Forms are completed.

Figure 8. Example of Form 3, Seasonal Data For Season Number 1

FORM 3
SEASONAL DATA

Airport Name	Tri-City State
Season No	1

TOTAL WEEKS IN SEASON	N	13
WEEKS SAMPLED IN SEASON	n	2
DAYS IN WEEK	M	7

	(A)	(D)	(E)	(K)
WEEK	AVERAGE DAILY OPERATIONS (FORM 2,(D))	COLUMN (A)-(C)	COLUMN (D) SQUARED	FROM FORM 2, (G)
1	10.86	2.86	8.18	406.86
2	5.14	-2.86	8.18	102.86
3				
4				

(B) 16.00 — Sum Col. (A)

AVERAGE DAILY OPERATIONS FOR SEASON (C) 8.00 — (B) ÷ n

Use to Calculate Col (D)

Transfer to Form 4 Col (H)

(F) 16.36 — Sum Col. (E)	(L) 509.72 — Sum Col. (K)
(G) 1 — n-1	(P) 12 — n x (M-1)
(H) 16.36 — (F) ÷ (G)	(Q) 42.48 — (L) ÷ (P)
(I) 12 — (N-1)	(R) 78 — N x (M-1)
(J) 196.32 — (H) x (I)	(S) 3313.44 — (Q) x (R)

(T) 3509.76 — (J) + (S)

(U) 90 — (NxM) - 1

(V) 39.00 — T ÷ (U)

Transfer to Form 4 Col (K)

Complete a separate Seasonal Data Form for each season. For example, if the year is divided into four seasons, then a total of four Seasonal Data Forms are completed. More rows may be added to Form 3 if more than four weeks are sampled in the season.

Figure 9. Example of Form 4, Annual Estimates

FORM 4
ANNUAL ESTIMATES

Airport Name	TRI - CITY STATE
Sample Period From	7/83 To 6/84

SEASON	(A) TOTAL DAYS D	(B) D^2	(C) SAMPLED DAYS d	(D) $\frac{D^2}{d}$	(E) $\frac{d}{D}$	(F) $1 - \frac{d}{D}$
1	92	8464	14	604.57	.15	.85
2	92	8464	14	604.57	.15	.85
3	91	8281	14	591.50	.15	.85
4	91	8281	14	591.50	.15	.85

SEASON	(G) TOTAL DAYS D	(H) AVERAGE (FORM 3, (C))	(I) TOTAL (G) x (H)
1	92	8.00	736.00
2	92	4.57	420.44
3	91	6.76	615.16
4	91	5.52	502.32
		ANNUAL OPERATIONS	(J) 2274 (Sum of Col. (I))

SEASON	(K) FROM FORM 3, (V)	(L) $\frac{D^2}{d}$	(M) COLUMN (K) x COLUMN (L)	(N) $1 - \frac{d}{D}$	(O) COLUMN (M) x COLUMN (N)
1	39.00	604.57	23578.23	.85	20041.50
2	18.85	604.57	11396.15	.85	9686.73
3	99.17	591.50	58659.06	.85	49860.20
4	21.68	591.50	12823.72	.85	10900.16

t-VALUE CHART
Find Lowest Value of d from Column (C)

If d 1	then	t
3		3.182
4		2.776
5		2.571
6		2.447
7		2.365
8		[illegible]
9		2.262
[illegible]		[illegible]
11		2.201
[illegible]		[illegible]
13		2.160
[illegible]		[illegible]
15		2.131
[illegible]		[illegible]
17		2.110
[illegible]		[illegible]
19		2.093
[illegible]		[illegible]
30		2.042
[illegible]		[illegible]
50		2.009
[illegible]		[illegible]
80		1.990

VARIANCE OF OPERATIONS	(P) 90488.59 (Sum of Col. (O))
	(Q) 300.81 ($\sqrt{(P)}$)
t-VALUE FROM CHART	(R) 2.16
95% CONFIDENCE INTERVAL	(S) 650 ((Q) x (R))
PERCENT SAMPLING ERROR	(T) 28.6 ((S) ÷ (J) x 100)

5. ESTIMATING DISTRIBUTIONS OF OPERATIONS

Often the distribution of operations over various time periods, or by type of operation, is as important as the estimate of total annual operations. An estimate of daily peak operations, for example, is needed to plan for airport capacity improvement projects. For many types of decisions the distribution of operations between local and itinerant operations may be almost as significant as total operations.

Distributions of operations that can be estimated include:

1. Distributions of operations across various time periods, including seasons, months, and weeks;
2. Frequency distributions and peak period estimates, including peak day or hour, and number of days exceeding a specified level of operations; and
3. Distributions of operations by type, including local/itinerant distribution, by aircraft type, and by runway or direction.

Estimate Seasonal and Monthly Distributions

Seasonal distributions may be determined by dividing the estimates of operations for each season by the annual estimate. For example, at Tri-City State Airport estimates of operations in each of the four seasons are 736, 420, 615, and 502, respectively. The seasonal distribution of operations is:

Summer	Fall	Winter	Spring
32%	19%	27%	22%

The distribution of operations indicates summer was the busiest season, as might be expected. The distribution also shows that winter had a larger share of operations than expected. Prior to the sample, winter was thought to have the lowest proportion of annual operations.

If a week of operations counts is obtained in each month, these data may be used to calculate the monthly distribution of operations. Average daily operations for each week sampled is multiplied by the number of days in the month to obtain total operations for the month. For example, at Tri-City State Airport average daily operations for the week sampled in August (10.86) multiplied by the number of days in August (31) equals estimated operations for August (336). Monthly operations estimates are divided by total annual operations to calculate the monthly distribution of operations. The monthly distribution is useful in identifying peak month activity and the range between the high and low activity months. It is not possible to construct a monthly distribution of operations for Tri-City State Airport because sample data was not obtained in all months.

Estimate Frequency Distribution and Peak Operations

If the sample is seasonally proportional, the sample data can be used to estimate the frequency distribution of operations and peak operations. A frequency distribution of daily operations is a tally of how often a given number of daily operations occurred during the sample. For example, it might indicate that 10 percent of the days sampled had 0-10 operations, 15 percent of the days sampled had 11-20 operations, 20 percent of the days sampled had 21-30 operations, etc. The distribution of sampled operations can be assumed to reflect the distribution of all operations.

Peak daily operations is the highest number of operations that was counted during a single day sampled. True peak daily operations will be at least as high as the peak observed from the sample data. There is no statistically reliable way to determine how much higher, if any, the true peak is.

The frequency distribution of hourly operations and peak hourly operations can also be determined in the same manner, if information about time of operation is collected during the sample.

Estimate Distribution of Operations by Type

If information about operations, such as aircraft type, is collected for each operation during the sample, then the distribution of operations by type can be determined in the same manner as the seasonal distribution. For example, at Tri-City State Airport there were 422 total fixed wing operations counted during the sample, which included 346 single engine, 76 multi-engine, and no jet aircraft. The distribution of operations by aircraft type is determined by dividing the operations for each aircraft type by total operations:

Single Engine	Multi-Engine	Jet
82%	18%	0%

Distributions can be calculated in the same way for any characteristic of operations that was collected during the sample.

Often information is desired about operations, but is too costly to collect for every operation counted. For example, identifying operations as local or itinerant is often desired, but requires a costly visual count to obtain the information. If funding is not adequate to conduct the entire sample using visual observation, the sample may be collected using a less expensive method, but augmented with a visual subsample of operations that are identified as local or itinerant. For example, two days out of each week sampled can be randomly subsampled for a visual count of operations. If the split between local and itinerant operations is expected to be different on weekdays and weekends, then both weekdays and weekends should be proportionally included in the visual subsample (e.g., two weekdays and one weekend day). At least two days must be subsampled from each week in order to estimate the precision of the estimate made from the subsample. The same number of days should be subsampled out of each week. The total size of the subsample will vary for the situation. In general, the larger the subsample the more accurate will be the result, but a good rule of thumb is to subsample at least 20 days out of the larger sample.

The proportion of local operations is determined by dividing the number of local operations counted by the total number of operations visually counted in the subsample. The proportion of itinerant operations is found in the same way.

The proportion of local and itinerant operations found in the subsample can then be applied to the larger sample. For example, if the visual subsample indicates 70 percent of the visually counted operations were local and 30 percent were itinerant, then total annual operations estimated from the large sample also can be assumed to be 70 percent local and 30 percent itinerant. The proportion of local and itinerant flights determined from a small subsample should only be applied to annual operations. The same proportional split may not hold for quarterly or monthly operations.

Additional information about this type of subsampling, called subsampling for proportions, can be found in a sampling textbook.[6]

Estimate Distribution of Operations Using Independent Data

If sufficient sample data is not available to directly calculate the seasonal or monthly distribution of operations, then independent data, such as weather, fuel sales, or tower data, may be used as a proxy. It should be noted that independent data is used here to allocate or distribute an estimate of annual operations obtained from sample data collected throughout the year. It is not used to expand one small sample of operations to estimate annual operations, which was identified as an unreliable technique in the introduction.

In order to use independent data to measure the changes in operations by season or month, three conditions must be met. First, there must be a theoretical basis or reason for believing that the independent data is related to operations and varies by month or by season in the same way that operations vary. For example, fuel sales at the airport or weather conditions at the airport can reasonably be expected to relate to operations.

Second, the independent data source must be accurate and complete. For example, fuel sales data may be closely related to operations if all fuel sales are reported and reported for the period in which they occurred. However, if private fuel tanks are used and not reported with fuel sales for the airport, the perceived relationship will not be accurate.

Third, the assumed relationship must be statistically established for the time period for which the distribution is reported. A correlation coefficient is a simple statistical measure of how closely independent data is related to operations. The user determines whether the correlation coefficient is satisfactory; that is, whether the independent data and operations are sufficiently related. The correlation coefficient ranges from -1.0 (independent data and operations move in opposite directions) to +1.0 (independent data and operations move together). The higher the correlation coefficient, the better the relationship.

Once an acceptable correlation has been established, independent data may be used to allocate the annual operations estimate. Fuel sales provide an example of how this is done. The example assumes monthly fuel sales data are available. First, the percent of total annual fuel sales (in gallons) that was sold in each month is calculated. The percent of annual fuel sales that was sold in each month is then applied to total annual operations to estimate operations for each month. For example, if 20 percent of total annual fuel sales occurred in July, then 20 percent of total annual operations would be allocated to July. Monthly operations can be added to derive seasonal operations.

In some cases it may also be possible to use the relationship between independent data and operations to estimate operations during years that sample operations data are not collected. This procedure assumes that the relationship observed between independent data and sampled operations at a particular airport throughout one year, or preferably over a number of years, continues to hold in a subsequent year. For example, the ratio of operations per gallon of fuel sold at an airport is calculated for each month for which there are sample operations counts. Average operations per gallon is then calculated for the year. The average operations per gallon ratio is used to estimate operations in subsequent years by multiplying the ratio times the number of gallons sold in the year being estimated.

[6]For example, see Sampling Techniques, William G. Cochran, Second Edition, pp 278-279

6. METHODS OF COLLECTING SAMPLE DATA

There are several methods that have been used to collect sample operations data. These include visual observations, pneumatic tube counters, inductance loop counters, and acoustical counters. Each method has its strengths and weaknesses in terms of accuracy, cost, ease of use, and ability to collect additional information about operations. Methods also differ in their suitability to the particular airport being sampled. Each of the methods is described briefly. More detailed information can be obtained from states identified as using a particular counting method, or from operation manuals available from the manufacturers of the mechanical counters. Table 4 at the end of the chapter provides a summary comparison of the different counting methods.

Visual Observation

Visual observation relies on observers physically present at the airport to count operations. It is the most accurate counting method, subject only to human error. However, observers must be trained to ensure the counts are consistent and complete. While it is possible to conduct visual counts 24 hours a day, it is most feasible to visually count operations during daylight hours, especially if additional information about operations is desired. This limitation may decrease the accuracy of the visual count, unless operations are known to occur only in daylight hours.

Visual observation is a relatively expensive way to collect sample data, since workers must be hired to make the observations. Costs may be reduced if volunteer or low-cost labor is available. However, if volunteer observers are used, it may be difficult to control the consistency and accuracy of the counts.

It is possible to gather a variety of information about operations counted using visual observation. Information can include time of operation, type of operation, or type of aircraft. If additional information is desired, the observer must be trained in how to consistently identify the desired characteristic, such as a local or itinerant flight.

Visual observation is most suitable at airports that have operations concentrated in an 8 to 12 hour daylight period. Airports with multiple or widely spaced runways may require more than one observer, expecially if additional information about operations is being collected.

In spite of its accuracy and ease of use, visual observation has not been widely used. This is because of the high cost for even a small sample of operations. Cost becomes even more critical if a 10 or 12 week sample of operations is required.

Virginia has used visual counts by Civil Air Patrol volunteers. Operations were counted only once a year during peak activity periods. The counts were used to determine the percent change in activity from one year to the next, not to estimate total annual operations.

In 1981 Florida estimated annual operations at 28 airports using visual observation. Two people visually counted operations at each airport from 7 AM to 7 PM on seven consecutive days. The sample data were expanded to estimate annual operations using independent factors, such as based aircraft and fuel sales. Additional information about operations, aircraft, passengers, and weather was also collected during the visual survey.[7]

The cost of Florida's 1981 counting program was about $1,000 to $1,200 per airport. Most of the cost was for the survey crew, but costs also included editing and analysis of the sample data.

Pneumatic Tube Counters

Pneumatic tube, or highway, counters were one of the first mechanical devices used to count aircraft operations. The device consists of a rubber tube attached to a counter. As an aircraft rolls over the tube air pressure registers a count on a paper tape.

Placement of the tube is critical to obtain an accurate count of operations. Because of excessive wear of the tubes when placed across the runway, tubes are often placed across taxiways leading to runways. Therefore, the counts recorded are actually of ground movement to and from runways. When placed on taxiways pneumatic tubes cannot count touch-and-go's or missed approaches. An estimated ratio of touch-and-go operations to counted operations is needed to separately estimate touch-and-go's from the counter operations data. This limitation reduces the accuracy of pneumatic tube counts. When tubes are placed across the runway, they still may not count all operations. Usefulness of pneumatic tube counters is further reduced because they cannot distinguish between type of operation and between aircraft and non-aircraft vehicles.

Pneumatic tube counters cost about 30 cents a foot for the rubber tube, plus $110 to $1,900, depending on the sophistication of the counter that is hooked to the tube. The least expensive counter registers counts with about a four percent error. This is a measure of mechanical error and is in addition to the error due to limitations from the placement of the tube and interpretation of the counter data. The more expensive counters register counts with less than a one percent error and provide day and time of count as well. The total cost of counting operations at an airport using pneumatic tubes depends on the number of runways and taxiways that must be counted.

[7]Florida Airport Activity Survey 1981, Division of Planning, Florida Department of Transportation.

Texas used pneumatic tube counters in 1972 and 1973 to count operations during two to three-week sample periods. Tower operations data were used to expand the sample data to estimate annual operations. Touch-and-go operations were estimated separately, based on an estimate by the airport manager of daily touch-and-go's. Texas has since discontinued the use of pneumatic tube counters.[8]

Michigan has used the Abrams Aircraft Counter for 20 years. The pneumatic tubes are placed across taxiways leading to runways. The Abrams Counter counts movement in one direction only and is set to count aircraft taxiing to the runway for departure. Registered counts are doubled to represent total operations. About 40 airports are counted each year. Each airport is counted for six to eight consecutive weeks during the spring, summer, or fall. The sample data is expanded using "M" factors to estimate total annual operations. "M" factors were calculated during the mid-1960's from tower operations data to account for the seasonal fluxuation in annual operations. Since touch-and-go's cannot be counted directly, they are estimated to be 35 percent of the total counted operations and are added to the counter operations estimate. The total annual estimate is then split between itinerant and local operations using a standard 35/65 percent split, unless the airport manager provides a more accurate ratio.[9]

Michigan is planning to count ten control airports every year using new Golden River counters attached to inductance loops permanently installed in the taxiway or runway. Operations will be counted continuously at these ten airports.

The 23 new Golden River counters were purchased at a total cost of $50,000. Airports counted with the Abrams counters cost an average of $360 each to count, including $210 for field and office staff time and $150 for maintenance of the counters.

Inductance Loop Counters

The inductance loop is another type of highway counter that has been used to count aircraft activity. Unlike the pneumatic tube, which is portable, the wire inductance loop is installed in the pavement of the runway or taxiway. It can be attached to the same type of counter device as used with the pneumatic tube. Operations are counted electronically as aircraft roll over the loop or fly over the loop within three feet of the surface. Loops can encompass a maximum of 180 square feet of surface area in which aircraft can be counted.

Like the pneumatic tube, correct placement is critical to obtain accurate counts. Even though the loop may be placed directly on the runway, the same limitations of pneumatic tubes exist with loops: they cannot count missed approaches, they likely will not count all touch-and-go's, they cannot distinguish between aircraft and other vehicles on the runway, and they cannot distinguish between landings and departures. Count accuracy could be improved by using a number of loops on the runway and on access taxiways; however, the cross-interpretation of data from all counters would be complex. Given the potential for missed operations and incorrect interpretation of the counts obtained, the suitability of the inductance loop is limited to short runways with limited access. Even in this case not all touch-and-go operations may be counted.

An inductance loop costs about $630, including installation, plus $110 to $1,900 for the counter device, depending on its sophistication. Increased runway maintenance costs are also incurred because of increased deterioration of the runway pavement around the area of installation.

Massachusetts has used inductance loop counters. The loops were believed to be at least as accurate as pneumatic tubes and more durable. Loops were installed 700 to 800 feet from each end of the runways in an attempt to count most landings and departures. Loops were initially installed only on the runway, but it was recognized that counts could be improved if loops or rubber tubes were also placed across access taxiways.[10]

Acoustical Counters

Acoustical counters use a microphone near the runway to pick up the sound of a departing aircraft at full engine power. The sound is recorded by a tape recorder and registered on a digital counter or a microprocessor memory. The recorded tape is then edited to pick out only the sounds of aircraft departures, including touch-and-go's and missed approaches. Departures are doubled to represent total operations. Total operations are not counted directly because quiet landings normally are not picked up by the microphone.

Acoustical counters are capable of accurately recording all departures if they are placed along the runway within their performance standards. Performance standards are adequate for most general aviation airports. If they are placed too far away from the path of departing aircraft, they may not record the departure or not record it distinctly.

Although the acoustical counter accurately records aircraft sounds, the correct interpretation of the recordings is necessary to ensure accurate operations counts. Interpretation of the recordings is necessary to ensure all the departures recorded are identified and counted as departures, but that non-departure sounds are not

[8]Annual Aircraft Terminal Operations Counting Program for Nontower Airports, Texas Airport System Plan, Technical Note GA-7, C. Jay Lyons and Robert J. Hammons, 1973; A Method of Expanding a Short Terminal Airplane Operation Count at Nontower General Aviation Airport to an Annual Estimate, Texas Airport System Plan, Technical Note GA-12, C. Jay Lyons, 1973.

[9]Michigan Aircraft Traffic Counter Program, Michigan Department of Transportation, April 1984.

[10]Status Report and Analysis of Inductance Loop Counting Method at Lawrence Municipal Airport, Massachusetts Aeronautics Commission, July1977.

mistaken for departures. With minimal training a person can distinguish between departures and other aircraft sounds and identify the type of aircraft departing, such as single engine, multi-engine, or jet. Helicopters can be detected by the counter, but operations cannot be estimated from the recorded sound of the helicopter. In addition to type of aircraft, day and hour of departure can also be determined from hourly time tones on the recorded tape.

The acoustical counter is relatively easy to use and is suitable for use at most airports (with up to 6,000-foot long runways). Some training is necessary on the operation of the counter and the optimal location of the counter near the runway. The counter is self-contained and weather resistant and may be left at an airport for several weeks to continuously count operations. Counters cost about $3,900.

Oregon has been testing and using acoustical counters since 1978. The counter is used to take week-long sample counts 4 to 12 times a year at each airport, depending on the activity level of the airport. The sample data is used to estimate annual, quarterly, and in some cases monthly, operations using standard statistical methods. One counter is rotated among several airports to maximize the use of each counter. Thirty-seven airports were counted during two years of sample counts.[11]

Airports cost an average of $1,200 each to count, including wages and mileage expenses; supplies; maintenance and repair of the counters; allocated capital cost of the counters; interpretation of the recorded tapes; data processing and analysis; and management of the program.

Small and remote airports are the most expensive to count because they require a larger sample size, longer driving time and higher mileage costs.

Utah is conducting a counting program similar to Oregon's. One week sample counts are taken during each season of the year. The sample data is expanded statistically to obtain annual operations estimates. During the 1983-84 counting period, six airports were counted with one counter. Total cost to collect the sample data and estimate annual operations was $17,189, or an average of $2,865 per airport. This does not include the cost of the counter, which was $3,225. Utah plans to count 18 airports with three acoustical counters during 1984-85. Estimated cost is $30,497, or $1,694 per airport, not including the cost of the counters.[12]

Arizona contracted with a consultant to count 30 airports and estimate annual operations in 1982-83. Six acoustical counters were used, which are owned by the consultant. Operations were counted during a two-week sample period. The sample data was expanded to an annual estimate of operations based on fuel sales (in dollars). The ratio of annual fuel sales during the previous year to fuel sales during the sample period is multiplied by the sample operations to obtain annual operations. For airports that did not have fuel sales or other independent data available, a linear projection of the sample data was made to estimate annual operations.[13]

Arizona's total cost of the count was $12,000, or $400 per airport. However, the consultant's actual cost to count 30 airports was $30,000, or $1,000 per airport.

[11]Aircraft Activity Counter Demonstration Project, Final Report, Aeronautics Division, Oregon Department of Transportation, 1982; Unpublished reports of airport operations estimates, Oregon Department of Transportation, 1984.

[12]Utah State Airport System Plan Update-1981(with revisions), Utah Department of Transportation, 1984.

[13]Arizona Airport Activity Survey 1982-83 of 30 General Aviation Airports, Vol. I Observations and Projections, Transportation Planning Division, Arizona Department of Transportation, June 1983.

Table 4. Comparison of Alternative Counting Methods

	Visual	Pnuematic Tube and Inductance Loops	Acoustical Counters
Ability to Count:			
Total Operations	Very accurate	Counts only operations that cross tubes	Counts fixed-wing take-offs,including touch-and-go's
Local/Itinerant Operations	Can be distinguished by trained observers	Cannot be distinguished	Cannot be distinguished
Aircraft Type	All classes can be distinguished	Cannot be distinguished	Distinguishes major classes: singles, multi's, jets and helicopters
Unit Cost	Not applicable	Up to $2,530. An airport may require more than one unit. Units can be rotated among airports	About $3,900. Units can be rotated among airports
Operating Cost	Very high if observers are paid	Relatively low	Relatively low
Major Advantage Compared to Other Methods	Very accurate. Can identify a variety of information about operations	Inexpensive	Inexpensive and more accurate than pnuematic tube
Major Disadvantage Compared to Other Methods	High cost	Least accurate. Only counts operations that cross tube or loop	Requires interpretation of recorded sounds

APPENDIX A
CORRECTIONS FOR LOSS OF SAMPLE DATA

The purpose of this appendix is to provide procedures for use when data are incomplete. When the sampling plan is developed as recommended and followed as closely as possible, problems interpreting data should be minimal. However, there are several problems that may occur as a result of loss of data. Lost data may result in incomplete clusters (normally weeks) or loss of entire clusters. Loss of entire clusters will eliminate proportionality of the sample and may leave a season with only one cluster of data from which to determine operations and variance. As long as there is at least one cluster or combination of incomplete clusters containing both weekdays and weekend days in each season, the data can be salvaged and a statistically valid operations estimate with a known degree of precision can be calculated.

Incomplete Clusters

As discussed previously, the use of week-long clusters eliminates biases that would otherwise result from weighting certain days of the week more heavily. Incomplete clusters may be used in calculation of annual and seasonal operations for an airport, but they must receive special treatment to ensure that biases are not reintroduced into the statistics.

If the cluster contains both weekdays and weekend days, then a fairly simple calculation, described in Alternate Procedure 1 at the end of this section, can be used to calculate several of the boxes in Forms 2 and 3. Once these calculations are made the remainder of the calculations can proceed.

If the cluster does not contain both weekdays and weekend days, then the daily operations data from that cluster will either have to be eliminated from consideration or combined with other cluster data. If the season in which the incomplete cluster lies already has two complete clusters, it will usually be best to discard the incomplete cluster and continue with calculations. If there are not two other complete clusters in the season, it may be desirable to combine all clusters in the season and calculate the seasonal average and variance as though the data came from a stratified random sample. Procedures for this type of calculation are contained in Alternate Procedure 2 at the end of this section. It will be necessary to have at least two weekdays and two weekend days represented in the combined sample in order to make calculations and to minimize inaccuracies. The results for the season can be entered on Form 4 to complete calculations of annual total operations and the sampling error.

If data within any one season is severly limited, as in the case of only one incomplete cluster, it may be appropriate to consider redefining seasons as described in Alternate Procedure 3, before using Alternate Procedure 2.

If, within any season, there are no clusters or combination of clusters containing both weekdays and weekend days, a statistically valid estimate of annual operations cannot be calculated for the airport.

Loss of Clusters

If whole clusters are lost or discarded, the sample may no longer be representative of the entire year and it may not be possible to complete a calculation of annual operations and the sampling error as described in the previous section.

If, after the loss of a cluster, there remains in each season at least two clusters containing both weekdays and weekend days, any bias introduced by the loss of the data will be so insignificant that calculations can continue using the standard procedures.

If some seasons are left with only one cluster, there are three options that may be pursued. The first option may be used only if clusters are evenly spaced throughout the year. If they are, then total annual operations and the sampling error may be calculated without stratifying by season, since proportionality of data will automatically reflect seasonal factors. These calculations are carried out with the standard forms as though all data came from one year-long season.

The second option is to redefine seasons as described in Alternate Procedure 3. If seasons can be redefined so that each season contains at least two clusters, then the standard procedures may be used to complete calculation of total operations and the sampling error.

If an attempt to redefine seasons is unsuccessful, then the third option is to use Alternate Procedure 4 to calculate average daily operations and variance for seasons with only one cluster. The results of this procedure can be used in Form 4 to complete standard calculations.

If some seasons are left with no clusters or combination of clusters containing both weekdays and weekend days, and if seasons cannot be redefined to eliminate the situation, then no statistically valid estimate of operations can be made for the airport.

INSTRUCTIONS FOR ALTERNATE PROCEDURE 1

This procedure is used to calculate intra-cluster average daily operations and variance for clusters not containing seven days. This procedure can be used only if the incomplete cluster contains both weekdays and weekend days. It can be adapted for any situation in which the cluster is not a multiple of seven days, including clusters of more than seven days.

To apply Alternate Procedure 1 use Worksheets 2a and 3a to calculate adjustments to Forms 2 and 3, respectively. Once these adjustments are made calculations may continue according to standard procedures.

Worksheet 2a: The purpose of this worksheet is to calculate an unbiased estimate of average daily operations for a week when the sample cluster is incomplete. (If the cluster consists of a full seven days, these calculations will yield exactly the same result as using Form 2 directly.)

Column (A) Enter total operations counted for each weekday sampled. There must be one or more entries in this column and it may have more than five entries if data cover a period longer than one week.

Box (B) Sum column (A) and enter the answer in box (B).

Box (C) Enter the number of weekdays sampled, normally between 1 and 5.

Box (D) Divide the sample total, box (B), by the number of weekdays sampled, box (C), and enter the answer in box (D).

Box (E) Multiply weekday average operations, box (D), by 5 and enter the answer in box (E). The purpose of this calculation is to develop a proportion. Therefore, it is correct to multiply by 5 even if the cluster covers a period of more than one week.

Column (F) Enter total operations for each weekend day sampled. There must be at least one entry in this column. If the cluster is more than one week, there may be more than two entries.

Box (G) Sum column (F) and enter the answer in box (G).

Box (H) Enter the number of weekend days sampled, normally 1 or 2.

Box (I) Divide the sample total, box (G), by the number of weekend days sampled, box (H), and enter the answer in box (I).

Box (J) Multiply weekend day average operations, box (I), by 2 and enter the answer in box (J). The purpose of this calculation is to develop a proportion. Therefore, it is correct to multiply by 2 even if the cluster covers a period of more than one week.

Box (K) Add box (E) and box (J) and enter the answer in box (K).

Box (L) Divide box (K) by 7 and enter the answer in box (L). This is the average daily operations for the week or weeks represented by the cluster sample. This number is transferred to Form 2, box (D).

WORKSHEET 2A
CALCULATION OF AVERAGE
DAILY OPERATIONS FOR FORM 2

WEEK DAY	(A) WEEKDAY OPERATIONS
1	
2	
3	
4	
5	

WEEKEND DAY	(F) WEEKEND OPERATIONS
1	
2	

SAMPLE TOTAL (B) — Sum Col. (A)

WEEKDAYS SAMPLED (C)

WEEKDAY AVERAGE (D) — (B) (C)

(E) — (D) x 5

SAMPLE TOTAL (G) — Sum Col. (F)

WEEKEND DAYS SAMPLED (H)

WEEKEND DAY AVERAGE (I) — (G) (H)

(J) — (I) x 2

(E) + (J) = (K) — (E) + (J)

AVERAGE DAILY OPERATIONS (L) — (K) 7

Transfer to Form 2 Box (D)

INSTRUCTIONS FOR ALTERNATE PROCEDURE 1, continued

Worksheet 3a: The purpose of this worksheet is to calculate "M" for use in Form 3, Seasonal Data, when Alternate Procedure 1 has been used to calculate the average daily operations for any of the sample clusters within the season represented by Form 3. "M" will be the average number of days per cluster.

Box D	Fill in the total number of days in the season.
Box d	Fill in the total days sampled in all clusters within the season.
Box n	Fill in the number of clusters sampled within the season. This number is transferred to the box n at the top of Form 3.
Box M	Divide d by n and enter the answer in box M. The result is the average days per cluster, M, and is transferred to the box M at the top of Form 3.
Box N	Divide D by M and enter the answer in box N here and at the top of Form 3.

When Worksheet 3a is used, the total number of clusters in the season in box N at the top of Form 3, will depend on the average size of the cluster, M. That is, N is determined by the total days in the season divided by M.

WORKSHEET 3A
CALCULATION OF M FOR FORM 3

TOTAL DAYS IN THE SEASON	D	
TOTAL DAYS SAMPLED IN THE SEASON	d	
NUMBER OF CLUSTERS SAMPLED IN THE SEASON	n	
AVERAGE DAYS PER CLUSTER	M d n	Enter as value for M in Box at top of Form 3
TOTAL CLUSTERS IN THE SEASON	N D M	

INSTRUCTIONS FOR ALTERNATE PROCEDURE 2

This procedure is used to calculate average daily operations and variance for a season in which there are incomplete clusters. The procedure combines all daily operations data in the season into a single sample, stratified by weekdays and weekend days. Application of the procedure requires that there be at least two weekdays and two weekend days sampled in the season.

The following steps are needed for alternate procedure 2:[14]

1. Calculate the average daily operations for all weekdays, $\bar{y}_d$.
2. Calculate the sample variance for average daily operations for weekdays, $s^2(\bar{y}_d)$.
3. Calculate the average daily operations for all weekend days, $\bar{y}_e$.
4. Calculate the sample variance for average daily operations for weekend days, $s^2(\bar{y}_e)$.
5. Calculate the average daily operations for the entire season, $\bar{y}_{st}$, according to the formula:
   $$\bar{y}_{st} = \frac{5(\bar{y}_d) + 2(\bar{y}_e)}{7}$$
   Enter this number in Form 4, column (H).
6. Calculate the variance of average daily operations for the entire season, $s^2(\bar{y}_{st})$, according to the following formula:
   $$s^2(\bar{y}_{st}) = s^2(\bar{y}_d)\left(\frac{.5102}{n_d} - \frac{.7143}{N}\right) + s^2(\bar{y}_e)\left(\frac{.0816}{n_e} - \frac{.2857}{N}\right)$$
   Where:

   n_d = number of weekdays sampled in the season,
   n_e = number of weekend days sampled in the season, and
   N = total days in the season, both weekdays and weekend days.[15]

   Enter this number in Form 4, column (K).

[14] These steps require some knowledge of statistics to follow. If necessary, consult a basic statistics book for formulas to calculate averages and sample variances. With these two pieces of information the remaining calculations are straightforward.

[15] Cochran, pp. 93-94.

INSTRUCTIONS FOR ALTERNATE PROCEDURE 3

This procedure is used to redefine seasons. When some seasons are left with only a single data cluster it may be appropriate to consider ways to redefine seasons (post stratify data) so that each will have more than one cluster. This will permit the use of standard procedures for the calculation of annual operations and the sampling error.

First use Form 2 (or Alternate Procedure 1, if necessary) to calculate average daily operations for each cluster.

Based on expected seasonal variations and knowledge of the average daily operations of the various clusters, try to group consecutive months into seasons to minimize known and expected differences in daily operations. If post stratified data result in two clusters per season, then the standard procedures can be used to complete calculations of annual operations and the sampling error.

If it is not possible to logically redefine seasons to contain at least two clusters, and clusters are not evenly spaced throughout the year, use Alternate Procedure 4 to calculate average daily operations and variance for the season. If clusters are evenly spaced throughout the year, then it may be appropriate to calculate annual operations without seasonal statifications.

INSTRUCTIONS FOR ALTERNATE PROCEDURE 4

This procedure is used to calculate the sampling error when one or more seasons contain only one cluster. As discussed above, if some seasons contain only one cluster, the variance of the season cannot be calculated. On the other hand, if sample clusters are not evenly spaced throughout the year, seasonal estimates must be used in the calculation of total annual operations to avoid biasing the results. The solution to this dilemma is to use seasonal stratifications to calculate total annual operations, but combine all cluster data without regard to seasons to estimate the sampling error. In this case the estimate of total annual operations will usually be more precise than indicated by the sampling error.

The following steps are needed for Alternate Procedure 4:

1. Complete a Form 2 for each cluster.
2. Estimate average daily operations for each season using Form 3, column (A) and boxes (B) and (C). It is not necessary to complete all of Form 3 during this step.
3. Use Form 4, columns (G), (H), and (I), and box (J) to calculate total annual operations. It is not necessary to complete all of Form 4 during this step.
4. Divide total annual operations by 365 to get average daily operations for the year. Enter this number in box (C) of a new Form 3.
5. Fill in columns (A) and (K) of the new Form 3, combining all information from the previously completed Form 2's into a single Form 3 without regard to seasons.
6. Complete the new Form 3 using information recorded in columns (A) and (K) and box (C), and ignoring box (B). Enter the results of this calculation, box (V), into a new Form 4, column (K).
7. Enter the number from box (J) of the previously completed Form 4 in box (J) of the new Form 4. Enter 365 in column (A). Enter total days sampled for the entire year in column (C).
8. Complete the new Form 4 as though all data came from a single season to calculate the sampling error for the annual operations estimate.

APPENDIX B

STATISTICAL DERIVATION OF ESTIMATING PROCEDURES

The statistical equations below were used to develop the forms in Chapter 4. People familiar with statistical estimating procedures may find it easier to use the statistical equations than the forms. The estimating equations are appropriate for a stratified cluster sample. Cluster units are weeks; elements of the cluster are days.

Estimate of Annual Operations

Operations are first calculated for each stratum, h, then added for total annual operations.

For each stratum, h:

$$\bar{y}_i = \frac{\sum^{M_i} y_{ij}}{M_i}, \text{ where}$$

$\bar{y}_i$ = mean operations per day in the ith cluster,
y_{ij} = operations on the jth day in the ith cluster,
M_i = number of elements in the ith cluster.

$$\bar{y}_h = \frac{\sum^{n_h} \bar{y}_i}{n_h}, \text{ where}$$

$\bar{y}_h$ = mean operations per day in stratum h,
n_h = number of clusters sampled in stratum h.

$$\hat{Y}_h = \bar{y}_h D_h, \text{ where}$$

$\hat{Y}_h$ = estimated operations in stratum h,
D_h = total number of days in stratum h.

$$\hat{Y}_{st} = \Sigma \hat{Y}_h, \text{ where}$$

$\hat{Y}_{st}$ = total estimated annual operations from a stratified sample.

Estimate of Variance

The variance of operations in each stratum is estimated. Strata variance are then added for the estimate of variance of total annual operations.

For each stratum, h:

$$s_h^2 = \frac{(N_h - 1)\, s_b^2 + N_h (M_h - 1)\, s_w^2}{N_h M_h - 1}, \text{ where}$$

s_h^2 = estimated variance of stratum h,
N_h = number of clusters in stratum h,
M_h = number of elements in clusters in stratum h (if cluster size varies within the stratum, then *M_h can be approximated as* $M_h = \frac{\sum^{n_h} M_i}{n_h}$),

$s_b^2 = \frac{(\bar{y}_i - \bar{y}_h)^2}{n_h - 1}$ = variance between clusters in stratum h,

$s_w^2 = \frac{\sum^{n_h} \sum^{M_h} (y_{ij} - \bar{y}_i)}{n_h (M_h - 1)}$ = variance between elements within clusters in stratum h.[16]

Once s_h^2 is estimated for each stratum, it is expanded in the standard manner to estimate the variance of estimated operations for each stratum, h:

$$S^2(\hat{Y}_h) = \frac{N_h^2\, s_h^2}{n_h}(1 - f), \text{ where}$$

$S^2(\hat{Y}_h)$ = estimated variance of estimated operations in stratum h,
N_h = number of days in stratum h,
n_h = number of days sampled in stratum h,
$(1 - f)$ = finite population correction (fpc) factor ($f = \frac{n_h}{N_h}$). Fpc can be ignored if $f < 5\%$.[17]

For the variance of total annual operations:

$$S^2(\hat{Y}_{st}) = \Sigma S^2(\hat{Y}_h), \text{ where}$$

$S^2(\hat{Y}_{st})$ = *estimated variance of estimated annual* operations from a stratified sample.

[16]The variance equations are based on the discussion of analysis of variance for cluster samples in Cochran, pp. 239-241; and in Sampling Theory of Surveys With Application, P. V. Sukhatme and B. V. Sukhatme, Second Edition, pp. 222-227 and 231-232.

[17]Cochran, p. 25.

Confidence Interval

The confidence interval of the estimated annual operations is:

$$\hat{Y}_{st} \pm t_{a/2} \sqrt{S^2(\hat{Y}_{st})}\text{ , where}$$

$t_{a/2}$ = t-value at the a/2 probability level with n-1 degrees of freedom.

In a stratified sample, the degrees of freedom, (n-1), for choosing t will differ if the sample size differs among strata. Form 4 uses a conservative estimate of n-1 (noted as d-1 on Form 4) by using the lowest number of days sampled in any one stratum. Actually, the number of degrees of freedom will lie between the smallest value of (n_h -1) and their sum. The equation for calculating the effective number of degrees of freedom, n_e, is:

$$n_e = \frac{(\Sigma g_h s_h^2)^2}{\Sigma \dfrac{g_h^2 s_h^4}{n_h - 1}}\text{ , where}$$

$$g_h = \frac{N_h (N_h - n_h)}{n_h}\text{ .}^{18}$$

[18]Cochran, pp. 94-95.

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